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COEFFICIENT OF FRICTION IN THIN – SHEET ROLLING WITH REGARD TO STRIP'S TENTION AND INERTIAL FORCES IN DEFORMATION CENTRE

The problems of control over the process of rolling mill rolling thin strips for continuous high-speed mills. An algorithm for calculating the coefficients of friction in sheet rolling with the tension and inertial forces was given.
Keywords: *thin sheets rolling, inertial forces, the deformation, the coefficients of friction.*

Лєпорська Н.В. Коефіцієнт тертя при тонколистової прокатці з урахуванням натягу смуги і інерційних сил в осередку деформації. *Розглянуто проблеми управління процесом прокатного виробництва при прокатці тонких смуг на безперервних високошвидкісних станах. Наведено алгоритм розрахунку коефіцієнтів тертя при тонколистової прокатці з урахуванням натягу і інерційних сил.*
Ключові слова: *тонколистова прокатка, інерційні сили, осередок деформації, коефіцієнт тертя.*

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Лепорская Н.В. Коэффициент трения при тонколистовой прокатке с учетом натяжения полосы и инерционных сил в очаге деформации. *В статье рассмотрены проблемы управления процессом прокатного производства при прокатке тонких полос на непрерывных высокоскоростных станах. Приведен алгоритм расчета коэффициентов трения при тонколистовой прокатке с учетом натяжения полосы и инерционных сил.*

Ключевые слова: *тонколистовая прокатка, инерционные силы, очаг деформации, коэффициент трения.*

Formulation of the problem. The global economic crisis has put before us a lot of questions and problems, the answers to which, and the solution of which require the development of new approaches, the birth of new business concepts.

Of all the ways of metal forming rolling production the most common type because of the continuity of the process, high productivity and the possibility of obtaining products of different shapes.

Considering the real economic situation in Ukraine, we must use every opportunity of new technologies, leading to increased efficiency in the use of cold rolling thin strips and strips, improve the quality of the rolled metal, process optimization, and so on.

One of the urgent problems of modern rolling mill is a radical improvement in the quality of steel, developing the production cost profiles, thin and very thin strips and improvement of the process.

Analysis of the latest research and publications. In the technology of rolling steel sheet cold rolling mills in the modern metallurgical production uses a lot of technology to improve performance and reduce rolling energy-power parameters, reduction of roll wear, improve technical and economic indicators of production.

Practical development of new rolling mills and cold-rolled sheet with high surface finish allows us to generalize the work of authors in this area and the results of their research.

After analyzing all the external variables that have an impact on improving the efficiency of production of cold rolled special attention is paid to the coefficient of friction. Given the impact of the strip tension and inertial forces acting in the deformation zone during rolling can develop a system of performance indicators in the rolling and create a new algorithm for calculating the coefficient of friction on the basis of the above research.

The purpose of this paper is to provide the highest efficiency in the process of high speed rolling in the production of thin sheets and strips with the inertial forces acting in the deformation zone.

Presentation of the basic material. Known formulas for the calculation of the coefficient of friction when rolling the sheet does not take into account the effect of the inertial forces in the deformation zone - the main feature of high speed rolling. As shown in [1], the force of inertia in the deformation is directed against a movement bands and acts like the back tension (Fig.) and thus has a significant effect on the stress-strain state of the band. Together with the action interstand tension in rolling mills for continuous high-speed inertial forces have a significant impact on the diagrams of the distribution of pressure on the contact and friction along the length of the arc of contact.

To determine the effect of the inertial forces and interstand strip tension with the law of G. Amonton form the equation of equilibrium:

$$\int_{\gamma}^{\alpha} fpb_{\varphi}R\cos\varphi \cdot d\varphi - \int_{0}^{\alpha} pb_{\varphi}R\sin\varphi \cdot d\varphi - \int_{0}^{\gamma} fpb_{\varphi}R\cos\varphi \cdot d\varphi - \frac{Q_3}{2} + \frac{Q_n}{2} - \frac{F_u}{2} = 0, \qquad (1)$$

where $Q_з$ and Q_n – respectively the power front and back tension band;

F_u – the power of inertia in the deformation zone.

Given that the bandwidth $b_{\varphi} = const$ of the radius $R = const$ of the rolls and if it is assumed that the pressure $p = const$ of the rolls, then equation (1) can be written in the form:

$$pbR\int_{\gamma}^{\alpha} f\cos\varphi \cdot d\varphi - pbR\int_{0}^{\alpha} \sin\varphi \cdot d\varphi - pbR\int_{0}^{\gamma} f\cos\varphi \cdot d\varphi - \frac{\sigma_3 Hb - \sigma_n hb + \sigma_u hb}{2} = 0. \qquad (2)$$

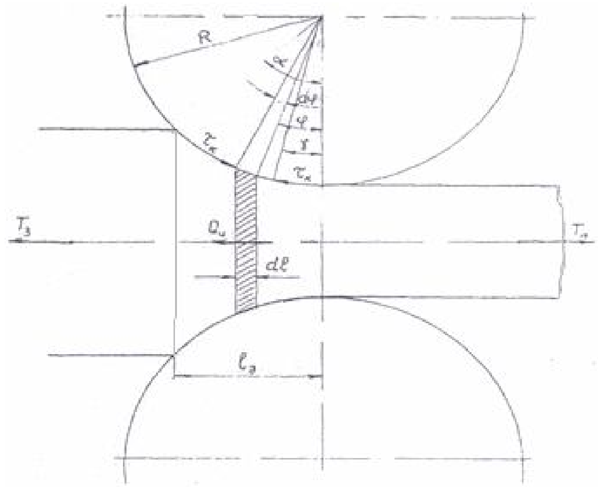

Figure – Scheme of the deformation zone, taking into account the inertial forces and the tension of the strip

Dividing each term of the equation (2) on *pbR*, we get:

$$\int_{\gamma}^{\alpha} f\cos\varphi\cdot d\varphi-\int_{0}^{\alpha}\sin\varphi\cdot d\varphi-\int_{0}^{\gamma} f\cos\varphi\cdot d\varphi-h\frac{\sigma_3\lambda-\sigma_{п}+\sigma_{и}}{2pR}=0\,. \tag{3}$$

If we assume that f = const and assume that it is possible to derive a formula for the calculation of neutral angle, taking into account the inertial forces and interstand strip tension:

$$\gamma=\frac{\alpha}{2}\left(1-\frac{\alpha}{2f}\right)-h\frac{\sigma_3\lambda-\sigma_{п}+\sigma_{и}}{4fpR}\,. \tag{4}$$

Using the known relationship $S_{н}=\frac{R\gamma^2}{h}$, and the formula (4) we obtain:

$$f=\frac{H\left[p(\lambda-1)+\sigma_{з}\lambda-\sigma_{п}+\sigma_{и}\right]}{2p\sqrt{HR\lambda(\lambda-1)}\left(1-2\sqrt{\frac{S_{н}}{\lambda-1}}\right)}, \tag{5}$$

where $\sigma_{з}$ and $\sigma_{п}$ – the voltage of the rear and front strip tension;

$\sigma_{и}$ – tension force of inertia in the exit plane of the deformed zone of the strip;

p – pressure metal rolls;

H – the initial thickness of the strip to pass;

λ – reduction factor;

R – radius of the work rolls;

$S_{н}$ – experimental advance with the influence interstand tension.

The inertial force occurring in the deformation area acts against the strip movement speed is determined by Newton's second law, the product of the mass of metal in the acceleration volume of the deformation.

Inertia can be defined by the formula [1]:

$$F_{и}=\rho v^2 bh_{ср}\frac{\ln\lambda}{\lambda}, \tag{6}$$

and the voltage of the inertial forces in the dangerous section - the exit plane of the deformation bands, can be calculated by the following formula (7):

$$\sigma_{и}=\frac{\rho v^2(\lambda+1)\ln\lambda}{2\lambda}, \tag{7}$$

where ρ – is the density of the rolled strip;

v – rolling speed;

h_{cp} – the average thickness of the strip in the deformation zone.

To calculate the coefficient of friction of the formula (5) rolling with tension bands you need to know a pilot ahead of the curve, which takes into account the impact interstand tension or use a known relationship [2] to determine the:

$$S_н = S_{on} - C_н \frac{Q_з - Q_п}{bh}, \quad (8)$$

where S_{on} – experimental advance without tension;

$C_н$ – constant for the slope of the line to the x-axis [2], that is $C_н = 1{,}2 \cdot 10^{-3}$.

Then the formula (8) can be written in the form:

$$S_н = S_{on} - C_н(\sigma_з \lambda - \sigma_п). \quad (9)$$

In a second embodiment form the equation of equilibrium with the friction conditions E. Siebel $f_1 = \frac{\tau_k}{2k}$:

$$\int_{\gamma}^{\alpha} 2kf_1 b_\varphi R\cos\varphi \cdot d\varphi - \int_{0}^{\alpha} p_\varphi b_\varphi R\sin\varphi \cdot d\varphi - \int_{0}^{\gamma} 2kf_1 b_\varphi R\cos\varphi \cdot d\varphi - \frac{Q_3}{2} + \frac{Q_п}{2} - \frac{F_u}{2} = 0, \quad (10)$$

where k – the resistance to pure shear bands.

Accept $k = 2k_{cp}$ $b_\varphi = b = const$ $p_\varphi = p = const$ $R = const$ $f_1 = const$ then we obtain:

$$-2k_{cp} f_1 bR\int_{\gamma}^{\alpha}\cos\varphi \cdot d\varphi - pbR\int_{0}^{\alpha}\sin\varphi \cdot d\varphi - 2k_{cp} f_1 bR\int_{0}^{\gamma}\cos\varphi \cdot d\varphi - \frac{\sigma_3 Hb - \sigma_п hb + \sigma_u hb}{2} = 0. \quad (11).$$

We receive quite reasonable assumptions:

$$\sin\gamma \approx \gamma, \sin\alpha \approx \alpha, tg\frac{\alpha}{2} \approx \frac{\alpha}{2}.$$

After integration and transformation of the equation (11) the formula neutral corner in the deformation zone:

$$\gamma = \frac{\alpha}{2}\left(1 - \frac{k_{нс}\alpha}{2f_1}\right) - h\frac{\sigma_3\lambda - \sigma_п + \sigma_u}{8k_{cp} f_1 R}. \quad (12)$$

Representing the average deformation resistance in the form $2k_{cp} = \frac{p}{k_{нс}}$ of formula (12) we obtain:

$$f_1 = \frac{k_{нс} H\left[p(\lambda - 1) + \sigma_з\lambda - \sigma_п + \sigma_u\right]}{2p\sqrt{HR\lambda(\lambda - 1)}\left(1 - 2\sqrt{\frac{S_н}{\lambda - 1}}\right)} \quad (13)$$

or

$$f_1 = \frac{H\left[p(\lambda - 1) + \sigma_з\lambda - \sigma_п + \sigma_u\right]}{4k_{cp}\sqrt{HR\lambda(\lambda - 1)}\left(1 - 2\sqrt{\frac{S_н}{\lambda - 1}}\right)}. \quad (14)$$

Mean deformation resistance for each pass band of the mill is determined by formula [1]:

$$2k_{cp} = 2k_o + \left(\frac{2}{\sqrt{3}}\right)^{n+1} \cdot \frac{П}{n+1} \frac{\left(\ln\frac{H_o}{h_i}\right)^{n+1} - \left(\ln\frac{H_o}{H_i}\right)^{n+1}}{\ln\frac{H_i}{h_i}}, \quad (15)$$

where H_o and H_i – are respectively and the thickness of the rolled strip in front of a pass-th;

h_i – the thickness of the strip after-crossing;

N and *n* – unit respectively and hardening strength indicator strip;

k_o – resistance to pure shear bands before rolling.

The algorithm for calculating the coefficients of friction below:

1. We introduce $H_0, H_i, h_i, \Pi, n, p, \sigma_{mo}, R, S_{on}, C_н, \sigma_з, \sigma_п, \rho, \nu$.
2. Print $H_0, H_i, h_i, \Pi, n, p, \sigma_{mo}, R, S_{on}, C_н, \sigma_з, \sigma_п, \rho, \nu$.
3. We compute $\lambda = \frac{H_i}{h_i}$, $S_н = S_{on} - C_н(\sigma_з \lambda - \sigma_п)$, $2k_o = \frac{2}{\sqrt{3}}\sigma_{mo}$.
4. We compute

$$2k_{cp} = 2k_o + \left(\frac{2}{\sqrt{3}}\right)^{n+1} \cdot \frac{\Pi}{n+1} \frac{\left(\ln\frac{H_o}{h_i}\right)^{n+1} - \left(\ln\frac{H_o}{H_i}\right)^{n+1}}{\ln\frac{H_i}{h_i}}.$$

5. Computable $\sigma_u = \frac{\rho \nu^2 (\lambda+1)\ln\lambda}{2\lambda}$.
6. Print $\lambda, S_н, 2k_o, 2k_{cp}, \sigma_u$.
7. Computable

$$f = \frac{H_i\left[p(\lambda-1) + \sigma_з \lambda - \sigma_п + \sigma_u\right]}{2p\sqrt{H_i R \lambda(\lambda-1)}\left(1 - 2\sqrt{\frac{S_н}{\lambda-1}}\right)}.$$

8. Computable

$$f_1 = \frac{H_i\left[p(\lambda-1) + \sigma_з \lambda - \sigma_п + \sigma_u\right]}{4k_{cp}\sqrt{H_i R \lambda(\lambda-1)}\left(1 - 2\sqrt{\frac{S_н}{\lambda-1}}\right)}.$$

9. Print f, f_1 .

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